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The evaluation of residual stress on the drawn wire using nano-indentation test

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Abstract

The residual stresses produced after wire drawing process have a harmful effect on the durability of the wire and become the cause which decreases the quality of the drawn wire. In this study, the influence of process parameters in the drawn wire on the residual stress was investigated by FE analysis. Based on the result of FE analysis, a residual stress relaxation method was suggested. The effectiveness of the suggested method was verified by the drawing experiment and the residual stress measurement through nano-indentation test.

Keywords: Residual stress; FE analysis; Residual stress relaxation method; Nano-indentation test

1. Introduction

Wire drawing is one of the most frequently applied technique in the wire manufacturing industry. Drawing operation involves pulling metal through a die by means of a tensile force applied to the exit side of a die to produce products of smaller-cross sections. Residual stresses are generated as a consequence of the non-uniform deformation associated to the process. It is known that the presence of residual stresses, especially tensile stress on the surface, may influence the mechanical behavior of the wires and their durability by reducing service life in stress corrosion cracking or fatigue [1,2]. Therefore, it is very important to reduce the residual stresses in the drawing process. In this study, the effects of the drawing process parameters on the residual stresses were investigated by using FE analysis. And in order to reduce the residual stress, not only the effects of skin pass and low semi-die angle but also the skin pass with low semi-die angle on the relaxation of the residual stresses were investigated. The effectiveness of the proposed method was verified through the wire drawing experiment and the measurement of the residual stress using nano-indentation test

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2. Effect of process parameters on the residual stress

In order to evaluate the effect of process parameters (semi-die angle (α), die reduction (R), friction coefficient (μ), and bearing length (l)) on the residual stresses, elasto-plastic FE analyses were carried out using DEFORM-2D [3]. The material properties of the applied high carbon steel (AISI1080) was obtained by tensile test as follows. In the FE analysis, the residual stresses were investigated at the end of drawing process in which the surface of the wire loses contact with the die. Therefore, the drawn wire was in a completely external load-free situation and the stresses were residual stresses. The conditions of FE analysis for the evaluation of the effect of process parameters on the residual stresses are summarized in Table 1.

Fig. 1 shows the results of FE analysis. The initial wire diameter is 2.0 mm. The larger semi-die angle increases the more tensile residual stress on the surface, because the larger semi-die angle leads to the more non-uniform deformation. In the relationship between die reduction and the residual stress, the larger die reduction from 5 to 25% causes less tensile axial residual stress on the surface and more compressive stress at the axis. However, the axis residual stress on the surface increases in the die reduction 30%. The hoop residual stress decreases according to the decrease in die reduction on the surface. In the analysis results, the effect of the friction coefficient of 0.04–0.10 on the distribution and magnitude of residual stress is insignificant.

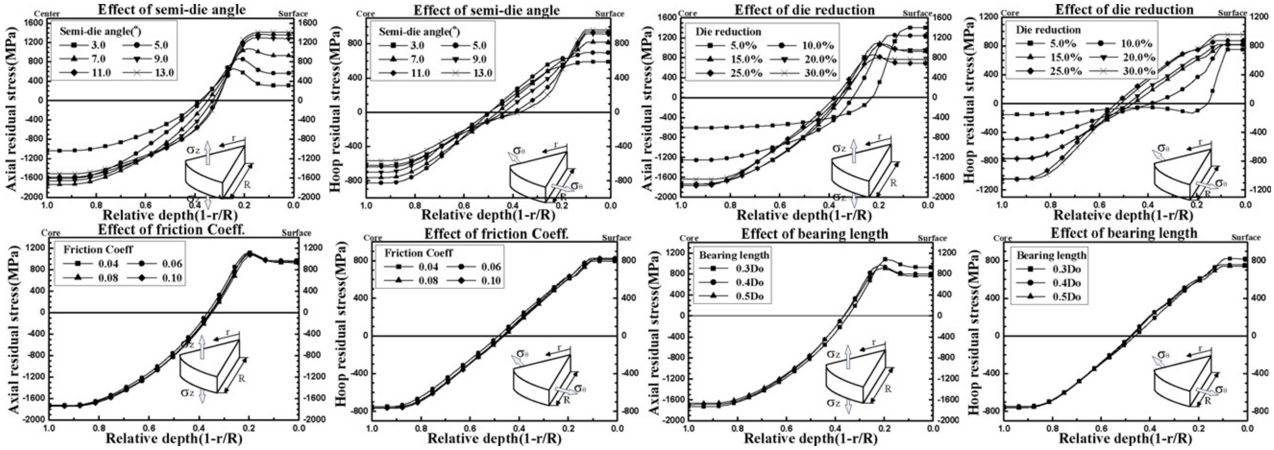

Fig. 1. The effect of the process parameters on the residual stresses.

Table 1
Drawing conditions for FE analysis to evaluate the effect of process parameters

Process parameter	Value
Semi-die angle (°)	3, 5, 7, 9, 11, 13 R: 15.0%, μ: 0.08, l: 0.3D$_o$ (D_o: initial wire diameter (2.0 mm))
Die reduction (%)	5, 10, 15, 20, 25, 30 α: 7°, μ: 0.08, l: 0.3D_o
Friction coefficient (μ)	0.04, 0.06, 0.08, 0.10 α: 7°, R: 15.0%, l: 0.3D_o
Bearing length (mm)	0.3D_o, 0.4D_o, 0.5D_o α: 7°, R: 15.0%, μ: 0.08
Material properties	$\bar{\sigma} = 3007.80\bar{\varepsilon}^{0.3175}$(MPa), E: 210 GPa, ν: 0.3

The longer bearing length somewhat decreases the axial and hoop residual stress on the surface, but the effect of the bearing length is insignificant. From these results, the effect of the friction coefficient and bearing length on the residual stresses is insignificant, but the effect of the semi-die angle and die reduction is significant.

3. Relaxation of residual stresses

3.1. Effects of skin pass and low semi-die angle on the residual stresses

In order to investigate the effect of the skin pass on the relaxation of residual stress on the surface of the drawn wire, after one pass drawing, four different skin pass reductions with the semi-die angle 7°, friction coefficient 0.08, and bearing length 0.3D_o were applied. Also, the effect of low semi-die angle was evaluated after one pass drawing. The conditions of FE analysis are summarized in Table 2.

Fig. 2 shows the results of FE analysis. In Fig. 2, the axial residual stress on the surface increases in the range of the skin pass reduction of 1–5%. However, the hoop residual stress decreases when the die reduction is 1%. Therefore, the low die reduction of skin pass is not sufficient to reduce the both axial and hoop residual stress on the wire surface. Also, in Fig. 2, application of low semi-die angle is effective in reducing the axial residual stress, especially in the semi-die angle of 1°, the resid-

Table 2
The conditions of FE analysis for the effect of skin pass and low semi-die angle

Process	Conditions	Value	Conditions	Value
1st pass	Semi-die angle Friction coefficient	7° 0.08	Bearing length Reduction	0.3D_o 15.0% (φ2.0 → φ1.844)
Skin pass	Semi-die angle Friction coefficient	7° 0.08	Bearing length Reduction	0.3D_o 1, 2, 3, 5%
Low semi-die angle	Semi-die angle Friction coefficient	1, 2, 3, 5° 0.08	Bearing length Reduction	0.3D 15.0% (φ1.844 → φ1.700)

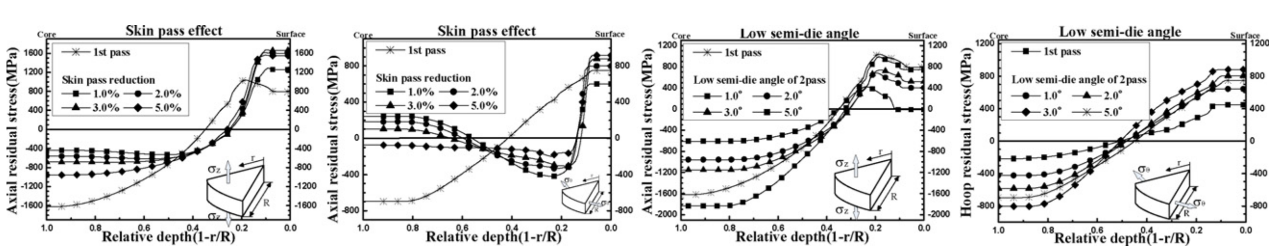

Fig. 2. The effect of skin pass and low semi-die angle on the residual stresses.